Treatment of Dairy Waste by Aeration
II. Continuous Aeration Studies*

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This paper reports the results of studies on continuous aerobic digestion of a simulated dairy waste. The general background of the work and the methods employed are summarized in a paper by Porges and Hoover in these Proceedings *(5)*§. Here is presented a rather detailed study of the basic biochemical reactions. Possible applications of the results of this study to industrial wastes are pointed out in the discussion.

The experiments were carried out in the laboratory with controlled temperature, aeration, and flow. The influent was added continuously at a fixed rate, and the effluent was sampled daily. In this way, the system was operated under balanced conditions. A complete solids balance was established by the methods described in *(5)*.

DESIGN OF EXPERIMENT

The aerobic fermenter described by Humfeld *(3)* was modified slightly by replacing the glass jar with a stainless-steel tank of about the same size. This fermentor, containing 20 liters of liquid to an overflow level, was kept in a water bath maintained at 30° C. Air was passed through the waste at a rate of 15-17 liters per minute. The aerator-stirrer mechanism thoroughly agitated as well as aerated the waste.

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§ Italicized figures in parentheses refer to entries in the Bibliography, page 144.

The inoculum was developed from a culture obtained at an activated-sludge plant which operates primarily on dairy wastes. This culture was propagated for several months in the system before the experiments began.

The simulated waste employed was a 0.100 percent solution of air-dry skim milk. The solids content was 970 ppm of solution (moisture-free basis). Table 1 shows the oxygen demand contributed by its con-

TABLE 1

COMPOSITION OF SIMULATED WASTE (O.1. PERCENT SOLUTION OF DRY SKIM MILK)

	Weight ppm	*COD*	
		Conversion Factor	*ppm*
Lactose	530	1.12	590
Protein	270	1.42	380
Other Substances	170	(by diff.)	80
Total	970		1,050

stituents. The "other" portion contains the inorganic salts, which contribute little or nothing to the oxygen demand, and the proteose and nonprotein-nitrogenous compounds, which are oxidizable but not precipitated as protein material in our method. The total chemical oxygen demand (COD) of 1050 ppm is close to the 20-day BOD of such a solution.

This simulated waste was fed into the fermentor for 24 hours a day by a constant-feed pump, and the effluent was drained off continuously by the overflow. The rate of addition was maintained at 1.0, 1.5, and 2.1 liters per hour; the average holding time was 20, 13.3, and 9.5 hours, respectively.

The pH of the simulated waste was that of a dilute solution of dried skim milk in water, about 6.8. During the second week of the experiment, the pH of the influent was adjusted to 10, to determine whether commonly-used alkaline washing agents would affect the microbiological flora.

RESULTS

Figure 1 shows the percentage of the original COD that remained each day, as well as the percentage of the original COD in the effluent

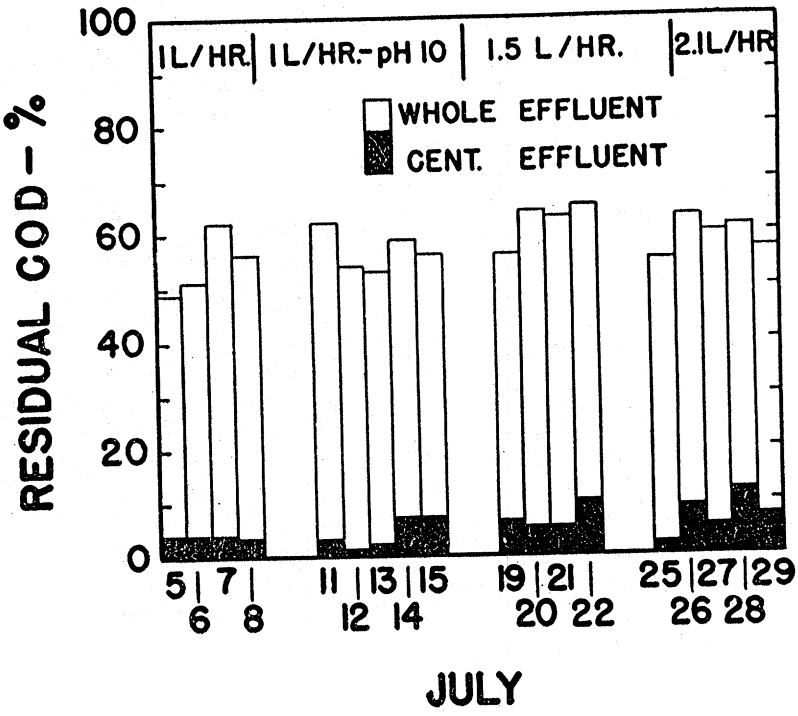

FIGURE 1.

after centrifuging. There was a 40 to 50 percent reduction in COD and an 89 to 98 percent reduction in the centrifuged effluent. The high rate of aeration and vigorous mechanical action produced a light, non-settling active flora, but it could be readily sedimented in a laboratory centrifuge. No further experiments were made on the separation of this "sludge".

The results for the first two weeks, when the pH of the influent was the only variable, were identical. The pH of the effluent was between 6.3 and 6.8 throughout the experiment, and averaged 6.5 during the second week. The results for these two weeks are therefore combined in Table 2, where average values are given for the decrease in lactose, protein, and COD of both the whole effluent and centrifuged effluent at the three rates of addition.

The lactose content of the effluent was zero throughout the experiment, despite the constant addition of a solution containing 530 ppm of lactose. The protein content of the effluent was essentially equivalent to the total content of nitrogenous materials (protein + proteose +

TABLE 2

COD OF EFFLUENT FROM THE AERATOR (1,050 PPM COD IN INFLUENT)

	Whole Effluent				Centrifuged Effluent			
Rate of Flow L/hr	Total COD ppm	Lactose COD ppm	Protein COD ppm	Other substances* COD ppm	Total COD ppm	Lactose COD ppm	Protein COD ppm	Other substances* COD ppm
1.0	585	0	335	250	40	0	6	34
1.5	635	0	400	225	60	0	16	44
2.1	630	0	350	270	88	0	24	64

* Obtained by subtracting the COD values of the lactose and protein from COD value of the total effluent.

nonprotein nitrogen compounds) in the influent. The third important finding was that the soluble organic matter of the influent had been either oxidized completely and thereby removed from the system, or had been assimilated into the cell tissue, which was removed by centrifuging the effluent. The centrifuged effluent contained no lactose and little protein. It must be remembered that these results are COD values; the 5-day BOD values of the centrifuged efflent would be appreciably lower.

The conclusion that the COD of the effluent was primarily due to the protein and carbohydratelike materials in the cells in suspension was confirmed by direct determination of the suspended solids. The determined values for protein and the "other substances" from the total COD values obtained by difference were converted to the weight basis by the appropriate factor. Table 3 shows the calculated values for suspended solids and those obtained by direct determination.

The calculated values for total suspended solids compare well with the values for determined suspended solids. This is not an exact calculation, for the residual dissolved solids are ignored and the use of the sugar factor for the "other substances" is arbitrary. Corrections for these two effects would be small, however, and would not alter the correlation markedly. Moreover, the primary purpose of Table 3 is to show that the methods used give a clear picture of the system at any time.

If these considerations are correct, the protein content of the recovered solids should be high, for no protein appears to be lost, although almost half the organic matter is dissipated. The composition of the solids, recovered by centrifuging and then dried, was therefore deter-

TABLE 3

COMPARISON OF CALCULATED AND DETERMINED SOLIDS IN THE EFFLUENT

Rate of Flow	*Protein*	*"Other Substances"*	*Suspended Solids*	
			Calculated Total	*Determined*
L/hr	*ppm*	*ppm*	*ppm*	*ppm*
1.0	236	223	459	480
1.5	282	201	483	470
2.1	246	241	487	.....

mined on one sample of each week's operation. Protein was assumed to be the total nitrogen multiplied by 6.25, the usual factor; carbohydrate was determined as glucose after a two-hour hydrolysis at 100° C in 0.75 *N* hydrochloric acid. It is expected that under these conditions the usual bacterial polysaccharides would be hydrolyzed but any resistant polysaccharides of the cellulose type present would not be attacked. Table 4 shows that the protein, carbohydrate, and ash constitute are approximately 90 percent of the cell weight and that, as expected, the protein content is high.

From these results and the original analytical data on the simulated waste, a balance on the organic solids can be established. In making these calculations, it must be remembered that the protein value in Table 1 is the true protein content, that is, the protein precipitable by trichloracetic acid. An appreciable portion of the nitrogenous compounds is not precipitated under the conditions of other analyses made but is available for protein synthesis by microorganisms. In Table 1,

TABLE 4

COMPOSITION OF SOLIDS (MICROORGANISMS) RECOVERED FROM EFFLUENT (MOISTURE-FREE BASIS)

Date Sampled July	*Protein percentage*	*Carbohydrate percentage*	*Ash percentage*
8	66.3	13.6	7.1
15	68.4	14.8	6.5
25	69.7	8.6	10.6
29	65.3	15.5	7.2

this portion, equivalent to about 80 ppm protein, is included in the "other substances." For the calculations of organic nutrients, therefore, 100 parts of air-dry skim-milk powder contain 53 parts of lactose and 35 parts of protein, a total of 88 parts of organic substrate for microbiological attack.

The amounts of the initial protein and carbohydrate in the cells are determined from the amounts of these materials recovered and from their composition (Table 4); the soluble constituents of the effluent are determined from the protein and COD values. The two parts of

TABLE 5

SOLIDS BALANCE SHEET IN AEROBIC ASSIMILATION

	Protein	*Carbohydrate*	*Total*
Influent	35	53	88
Effluent			
Solids (cells)	34	7	41
Soluble	1	2	3
Destroyed	0	44	44

"soluble carbohydrate" shown in Table 5 are an arbitrary assignment of the nonprotein COD to carbohydrate; more exactly, this amount is the "soluble nonprotein COD."

DISCUSSION

In this experiment, 45 to 48 percent of the organic nutrients was assimilated into cell substance, while 50 percent was oxidized to gain energy for the growth of cells. These values are in excellent agreement with the results of Ruchhoft, Kachmar, and Placak *(6)* on glucose oxidation and assimilation, and the results of the U. S. Public Health Service group on assimilation and oxidation of organic substrates by activated sludge, summarized in the recent publication of Placak and Ruchhoft *(4)*.

The results presented here also are in agreement with studies of microbial metabolism carried out by various workers *(1, 2, 7)*, who have shown that assimilation into cell substance is of primary importance in the growth process. The investigation reported in this paper is being continued and the discussion of the basic biochemistry of the process will not be given until the studies have been completed.

There are two major points, however, which deserve consideration by sanitary engineers. The first is that the extremely high rate of

assimilation of dairy wastes by microorganisms increases the oxygen demand of the flora greatly and, if this demand is met, dairy wastes and related strong organic wastes might be satisfactorily treated in conventional systems. If aerobic conditions are maintained, by-products of oxidation are negligible, and acids do not accumulate. The larger quantity of sludge produced would have to be either removed or further digested in the conventional manner.

The second point is illustrated in Figure 2, which both summarizes the results and shows schematically a possible system of dairy-waste

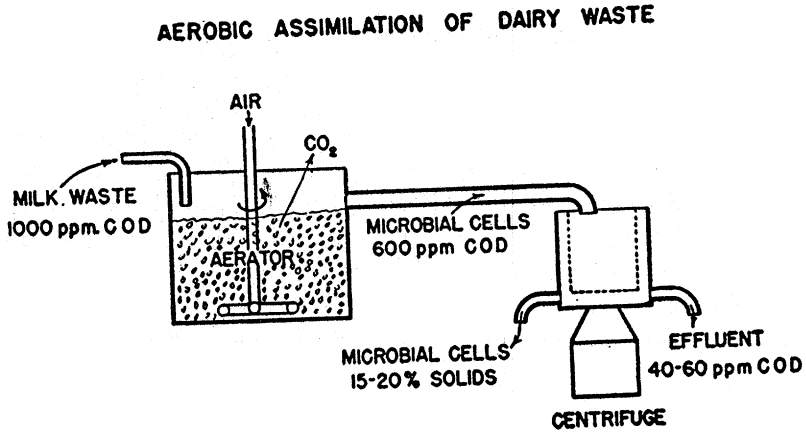

FIGURE 2.

disposal. A rapid aeration process followed by removal of the organisms gives a satisfactory effluent for discharge to a stream. The best methods of maintaining strongly aerobic conditions, removing the cells, drying them, and using them as fertilizer or possibly as feed deserve serious consideration.

SUMMARY

A simulated milk waste (0.1 percent solution of dry skim milk) was oxidized aerobically by a natural microflora under controlled temperature, aeration, and flow. The microorganisms oxidized 50 percent of the organic matter and assimilated 45 to 48 percent into their cell tissues.

Possible application of these results in sanitary engineering is discussed.

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